International Journal of Research and Application

ISSN (online): 2349-0020 http://www.ijraonline.com/

Research Article

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DOI:
http://dx.doi.org/
10.17812/IJRA.1.2(10)2014

Manuscript:
Received: 25th April, 2014
Accepted: 18th May, 2014
Published: 2nd June, 2014

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IJRA - Year of 2014 Transactions:
Month: April - June
Volume – 1, Issue – 2, Page No's: 50-53
Subject Stream: Electronics

Paper Communication: Author Direct

Paper Reference Id: IJRA-2014: 1(2)50-53

International Journal of Research and Applications
April - June © 2014 Transactions; 1(2): 50-53
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ELECTRONICS RESEARCH ARTICLE

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ABSTRACT
In this paper we consider the cooperative spectrum sensing , in which multiple number of cognitive radios collaborately detect the spectrum holes to use unused spectrum through the method of energy detector .The problem with the cognitive radio network is when the cognitive radio users are increasing ,it requires more sensing time.So here a fast spectrum sensing algorithm has been proposed ,in which requires fewer than the total number of cognitive radios in cooperative spectrum sensing.

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I. INTRODUCTION

From past few decades rapid increase in wireless applications requires a more spectrum resources to meet the new emerging wireless applications, but already existing spectrum is allocated to specific applications. So there is a spectrum scarcity to provide a new bandwidth to new wireless applications. A recent survey of the spectrum utilization made by the Federal communication commission (FCC) has indicated that large licensed spectrum is under utilized in the already existing applications.

Cognitive radio is a new technology, proposed recently it allocates unused radio spectrum from the primary users to the unlicensed users and also it is a intelligent device , has the ability to aware of radio frequency environment, based on which it automatically adjusts its parameters like carrier frequency, band width and transmission power to optimize the spectrum usage. The main problem with the spectrum sensing algorithm is hidden terminal problem, in which cognitive radio is shadowed, in severe multi path fading or inside building with high penetration loss while a primary user is operating in vicinity [1].So there is a possibility of accessing primary user spectrum by the cognitive radio due to hidden terminal problem. In order to avoid hidden terminal problem in cognitive radio networks, multiple cognitive users can cooperate to perform spectrum sensing [2].Here we consider the optimization of cooperative spectrum sensing with energy detection to minimize the total error rate. It should be mentioned that optimal spectrum sensing under data fusion was proposed in [3] where the optimal linear function of weighted data fusion has been obtained. In the recent works [4],[5] optimal sensing throughput was studied .optimal distributed signal detection with likelihood ratio test using reporting channels from the cognitive radios to fusion center has been studied in [6].

II. ENERGY DETECTOR

Energy detection is a signal detection mechanism based on Neyman-Pearson approach. The detector computes the energy of the received signal and compares it to certain threshold value to decide whether the desired signal is present or not. The energy of the signal is preserved in both time domain and frequency domain. Theoretically, whichever representation is used for signal detection and analysis makes no difference in result. However in the former representation a pre-filter matched to the bandwidth of the signal is required. This needs makes this representation quite inflexible compared to the frequency domain representation.

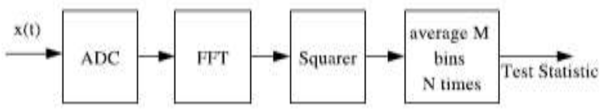

Fig.1. Frequency domain representation of energy detection mechanism.

In order to measure the signal energy, the received signal is first sampled, and then converted to frequency domain taking FFT followed by squaring the coefficients and then taking the average. The decision making strategy of energy detector is the test of two hypotheses H_0 and H_1. The decision value of the energy detector to compare with the threshold λ is given by

$$T = \sum_{n=0}^{N-1} |x(n)|^2; \qquad n = 0,1,2,.....N-1, N \qquad (1)$$

The averaged signal energy is then subjected to the test of the two hypotheses. H_0 is the null hypothesis meaning that the received signal comprises of the noise only. If H0 is true then the decision value given by will be less than the threshold. So the detector will conclude that there is no availability of the vacant spectrum. On the other hand, if H1 is true i.e. received signal has both signal and noise, the decision value will be larger than the threshold. So the detector concludes that the vacant spectrum is available. The threshold value is chosen so as to control the parameters such as probability of false alarm and probability of detection.

III. SPECTRUM SENSING

Hypothesis testing is a statistical test to determine the presence or absence of a PU. This test can be performed individually by each cooperating user for local decisions or performed by the fusion centre for cooperative decision.

In the following we only consider the spectrum sensing at CR i. The sensing method is to decide between the following two hypotheses,

$$x_i(t) = \begin{cases} w_i(t) & H_0 \\ h_i(t)s(t) + w_i t) & H_1 \end{cases} \quad (2)$$

H_0: primary user is absent;
H_1: primary user is in operation.

Where $x_i(t)$ is the received signal at the *i*th CR in time slot *t*, (*t*) is the PU signal, $w_i(t)$ is the additive white Gaussian noise (AWGN), and hi (*t*) denotes the complex channel gain of the sensing channel between the PU and the ith CR. We assume that the sensing time is smaller than the coherence time of the channel. Then, the sensing channel $h_i(t)$ can be viewed as time-invariant during the sensing process. Without loss of generality, we denote $h_i(t)$ as h_i. Moreover, we assume that the status of the PU remains unchanged during the spectrum sensing process.

If prior knowledge of the PU signal is unknown, the energy detection method is optimal for detecting zero-mean constellation[7] signals .For the *i*th CR with the energy detector, the average probability of false alarm, the average probability of detection, and the average probability of missed detection over AWGN channels are given, respectively, by[8]

$$P_{f,i} = \frac{\Gamma\left(u, \frac{\lambda_i}{2}\right)}{\Gamma(u)} \qquad (3)$$

$$P_{f,i} = Q_u\left(\sqrt{2\gamma_i}, \sqrt{\lambda_i}\right) \quad (4)$$

And $\quad P_{m,i} = 1 - P_{d,i}$.

In the above equations, λ_i and γ_i denote the energy detection threshold and the instantaneous signal-to-noise ratio (SNR) at the *i*th CR, respectively, u is the time-bandwidth product of the energy detector.

Where Γ (a, x) is the incomplete gamma function given by

$$\Gamma(a,x) = \int_x^{\infty} t^{a-1} e^{-t} dt \quad (5)$$

$\Gamma(a,x)$ Is a gamma function and $Q_u(a,b)$ is the generalized Marcum Q function given by

$$Q_u(a,b) = \frac{1}{a^{u-1}} \int_x^{\infty} t^u e^{-\frac{t^2+a^2}{2}} I_{u-1}(at) dt \qquad (6)$$

With I_{u-1} being the modified Bessel function of the first kind and order u-1. Cooperative spectrum sensing, each cooperative partner makes a binary decision based on its local observation and then forwards one bit of the decision *Di* (1 standing for the presence of the PU, 0 for the absence of the PU) to the common receiver through an error-free channel. At the common receiver, all 1-bit decisions are fused together according to logic rule

$$Y = \sum_{i=1}^{k} D_i \begin{cases} \geq n & H_1 \\ < n & H_0 \end{cases} \qquad (7)$$

The threshold 'n' is an integer, representing the "*n*-out-of K" voting rule. It can be seen that the OR rule corresponds to the case of n=1 and the AND rule corresponds to the case of n= K. We assume that, compared with the distance from any cognitive radio to the primary transmitter, the distance between any two cognitive radios is small, so that the received

signal at each cognitive radio experiences almost identical path loss. Therefore, in the case of an AWGN environment, we can assume that $\Upsilon_1 = \Upsilon_2 = \dots = \Upsilon_k = \Upsilon$.

Furthermore, we assume that all cognitive radios use the same threshold λ implying $\lambda 1 = \lambda_2 = \lambda_3 = \dots = \lambda_k = \lambda$. This results in $P_{f,i}$ being independent of i, and we denote it as P_f .In the case of an AWGN channel, $P_{d,i}$ is independent of i (we denote this as P_d).

The false alarm probability of cooperative spectrum sensing is given by

$$Q_f = prob\left(\frac{H_1}{H_0}\right) = \sum_{l=n}^{K} \binom{K}{l} P_f^l (1-P_f)^{K-1} \qquad (8)$$

The missed detection probability of cooperative spectrum sensing is given by

$$Q_f = prob\left(\frac{H_0}{H_1}\right) = 1 - \sum_{l=n}^{K} \binom{K}{l} P_d^l (1-P_d)^{K-1} \qquad (9)$$

A) Decision Fusion centre

In order to realize the cooperative detection among CR users, the spectrum sensing and signal detection information over individual users should be sent to a fusion centre for further process and the fusion centre makes the final decision whether primary user signal is present or absent. Since we discuss cooperative spectrum sensing under communication bandwidth constraints, it is proper that all cognitive radio users send their one-bit decision on spectrum sensing to Fusion centre based on their local observations. As described in Figure 2, information of local signal observation from all cognitive users transmits to data fusion centre. They forward 1-bit local detection to avoid communication overhead when CR users increased. Then, the final decision is performed whether signal is present (H1) or absent (H0) by regarding to decision rule.

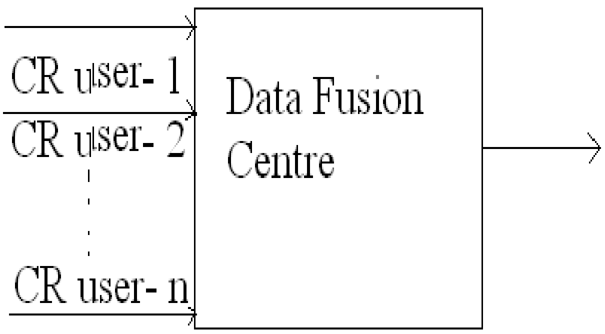

Fig. 2. Data fusion centre.

Information of local signal observation from all cognitive users transmits to data fusion centre. They forward 1-bit local detection to avoid communication overhead when CR users increased. Then, the final decision is performed whether signal is present (H1) or absent (H0) by regarding to decision rule.

IV. OPTIMIZATION OF COOPERATIVE SPECTRUM SENSING

In this section, we investigate the optimality of cooperative spectrum sensing when energy detection and decision fusion are applied. Suppose that (Total number of cognitive radio users) is fixed, what the optimal voting rule is, i.e., what is the optimal n, which we denote as n_{opt}, which minimizes the total error rate $Qf + Q_m$.

$$n_{opt} = \min\left(K, \left\lceil \frac{K}{1+\alpha} \right\rceil\right) \qquad (11)$$

where $\alpha = \dfrac{\ln \dfrac{P_f}{1-P_m}}{\ln \dfrac{P_m}{1-P_f}}$ and $\rceil$ denotes the ceiling function. The OR rule is optimal when $\alpha \geq k-1$. This means that P_f ⁚ P_m^{k-1} this implies that $P_f \ll P_m$ for a large value K. This can be achieved when the detection threshold λ is very large. The AND rule is optimal when $\alpha \to 0$. This is achieved when $P_m \ll P_f$, i.e., for a very small λ.

Let G be a function given by

$$G(n) = \sum_{l=n}^{K} \binom{K}{l} \left[P_f^l (1-P_f)^{K-1} - (1-P_m)^l P_m^{K-1}\right] \ (12)$$

We get $Q_f + Q_m = 1 + G(n)$

$$\frac{\partial G(n)}{\partial (n)} \approx G(n+1) - G(n)$$

$$= \binom{K}{n} \left[P_f^l (1-P_f)^{K-1} - (1-P_m)^l P_m^{K-n}\right] \ (13)$$

The optimal value of n is obtained when $\frac{\partial G(n)}{\partial n} = 0$

i.e., when

$$(1-P_m)^n P_m^{k-n} = P_f^n (1-P_f)^{K-n} \qquad (14)$$

Let $\alpha = \dfrac{\ln \dfrac{P_f}{1-P_m}}{\ln \dfrac{P_m}{1-P_f}}$ .Then we get

$$\approx \left\lceil \frac{K}{1+\alpha} \right\rceil \qquad (15)$$

V. SIMULATIONS

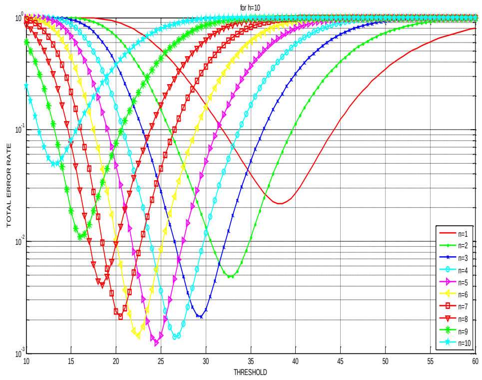

Fig. 3.Total Error Rate Vs Threshold at constant SNR 10 dB.Total error rate of cooperative spectrum sensing in 10 dB AWGN channel: voting rules are $n = 1, 2, 3 \ldots, 10$, $K = 10$. For SNR= 10 dB Total number of cognitive radio users K =10.

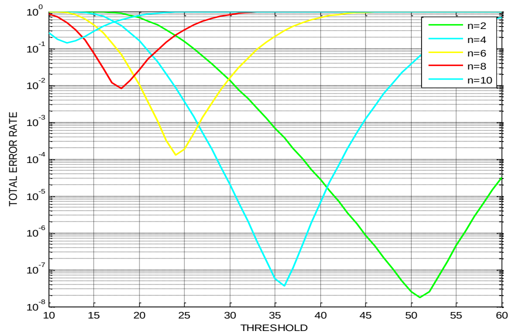

Fig. 4.Total Error Rate Vs Threshold for different SNR values.

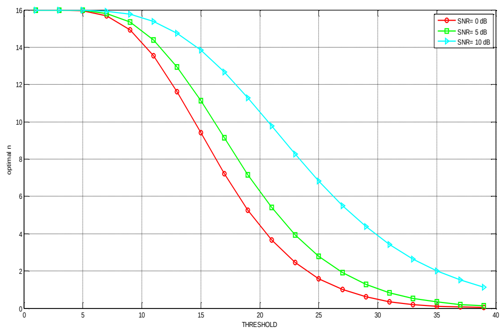

Fig. 5. Optimal voting rule versus detection threshold of cooperative spectrum sensing in AWGN channel with SNR = 0, 5, 10 dB, $K = 16$. SNR = 0 dB,SNR = 5 dB, SNR = 10 dB. Total number of cognitive radio users k= 16.

VI. CONCLUSIONS

We have studied the performance of cooperative spectrum sensing with energy detection in cognitive radio networks. It has been found that the optimal decision voting rule to minimize the total error probability is the half-voting rule. A method of numerically obtaining the optimal detection threshold has been presented. In addition, an efficient spectrum sensing algorithm has been proposed which requires fewer than the total number of cognitive radios in cooperative spectrum sensing while satisfying a given error bound.

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